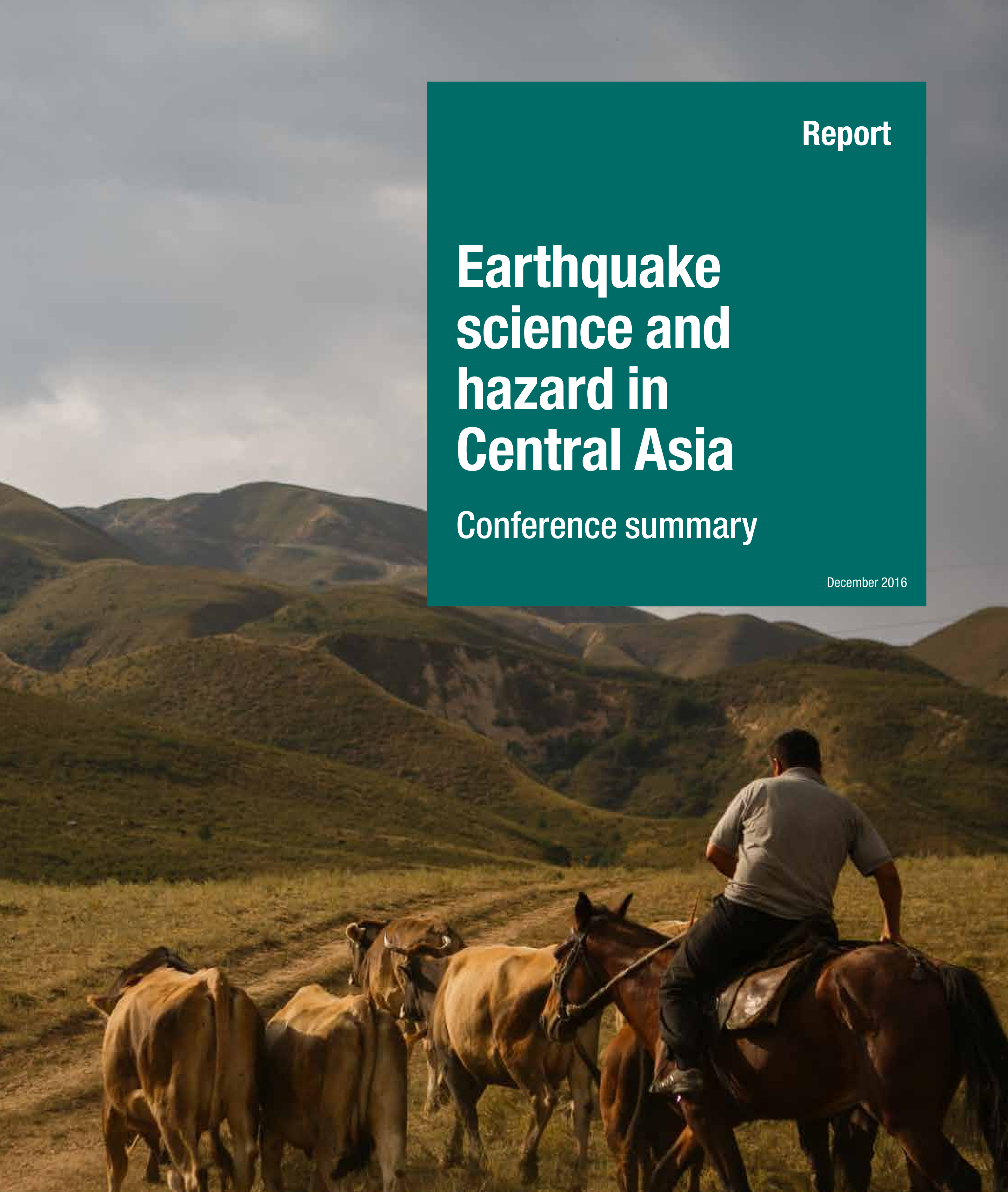

Report

Earthquake science and hazard in Central Asia

Conference summary

December 2016

EARTHQUAKES WITHOUT FRONTIERS

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Cover photo: Conference field trip to Ushkonyr, Kazakhstan. Victor Magdeyev/Shakhmardan Yessenov Foundation, 2016.

‘Earthquakes don’t care whether you’re Kyrgyzstani or Kazak, man or woman’ – Kanatbek Abdrakhmatov

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About this report

This report is the result of a three-day conference on earthquake science and hazard in Central Asia, sponsored by the Shakhmardan Yessenov Foundation and co-hosted by the Kazakhstan Institute of Seismology of the Academy of Sciences, the National Technical University of Kazakhstan, and the Earthquakes without Frontiers partnership.

The conference convened earthquake scientists from China, Germany, Kazakhstan, Kyrgyzstan, India, Iran, Italy, Nepal and the UK, and had three aims:

- to highlight modern techniques used to understand earthquakes in Central Asia
- to provide a forum to discuss and share strategies for the mitigation of earthquake risk
- to promote effective communication of earthquake science to policy-makers and the public.

Day 3 panel discussion (L-R) Tim Sim, Kanatbek Abdrakhmatov, Morteza Talebian and Nicola D'Agostino. Photo: Victor Magdeyev/ Shakhmardan Yessenov Foundation, 2016.

Day one of the conference looked at current, cutting-edge earthquake science in Central Asia. Participants presented a range of modern earthquake science investigations and techniques, and shared the findings of ongoing research in the Tien Shan region. Day two explored earthquake hazard assessment and approaches to risk mitigation. Participants from around Europe and Central Asia explained how science is used to inform earthquake policy and preparedness in their countries, and the effectiveness of these approaches. Finally, day three considered perceptions, policy and education in relation to earthquake risk, examining the lessons learned from days one and two, and how to apply that learning across Central Asia, in particular in the Tien Shan region. Participants discussed the effects and consequences of public and official responses to recent earthquakes, and the challenges and approaches in communicating earthquake science and risk-reduction strategies. The full conference programme and list of presenters can be found in Annex A.

Through the promotion and exchange of results and techniques, the conference sought to inspire, encourage and stimulate earthquake research in Kazakhstan, and raise awareness of realistic earthquake risk-reduction strategies.

This report synthesises the key messages emerging from conference presentations and discussions throughout the three days. It draws on material shared by the delegates, whose presentations can be found, in full, on the Shakhmardan Yessenov Foundation website at http://yessenovfoundation.org/science/research.

The Shakhmardan Yessenov Foundation

The Shakhmardan Yessenov Science and Education Foundation was created in 2013 to develop higher education, science and innovation in Kazakhstan. The Foundation's mission is to develop Kazakhstan's intellectual potential, and its activities focus on knowledge, science and resources. Some of the Foundation's most well-known programmes are:

- research internships in laboratories, IT start-ups and innovative enterprises around the world
- 'Yessenov Lectures' (guest lectures at universities)
- the Yessenov Scholarship
- the 'Komanda SOS' scheme, which creates and supports effective groups of volunteers to work on different social issues – from health to poverty – in Kazakhstan
- travel grants to young students
- publication of books and promotion of science
- promotion of chess in Kazakhstan.

For further information, see http://eng.yessenovfoundation.org.

Earthquakes without Frontiers

Earthquakes without Frontiers (EwF) is a partnership between researchers in UK universities and independent earthquake scientists and social scientists in countries throughout the great earthquake belt between Italy and China. The EwF partnership brings together earth scientists specialising in integrated earthquake science, social scientists with extensive experience of exploring the vulnerability and resilience of communities in disaster-prone regions, and experienced practitioners in the communication of scientific knowledge to policy-makers.

In Kazakhstan, EwF researchers are engaged in seismology and geological fieldwork, as well as social science programmes in south Kazakhstan. EwF's principal local partners are the Institute of Seismology of the Academy of Sciences, the Kazakh National Data Center (KNDC), the Kazakh Red Crescent Society and Taraz State University. For further information, see http://ewf.nerc.ac.uk (in English).

Acknowledgements

This report was written by Louise Ball and Hannah Caddick of the communications team in ODI's Research and Policy in Development programme (RAPID), who attended the conference on earthquake science and hazard in Central Asia in September 2016.

The authors would like to thank the conference co-hosts: the Kazakhstan Institute of Seismology of the Academy of Sciences, and in particular Tanatkan Abakanov; the National Technical University of Kazakhstan; and the Earthquakes without Frontiers partnership. They also thank conference sponsors and organisers, the Shakhmardan Yessenov Science and Education Foundation, particularly the founding members Galimzhan Yessenov and Aizhan Yessim for supporting the idea of holding the conference, and Aiganym Malisheva and Zhadyra Sarmanova, whose cooperation and support have been essential to the production of this report and its translation into Russian.

The authors give special thanks to James Jackson, Professor of Active Tectonics at University of Cambridge and Earthquakes without Frontiers project lead, for convening the conference and for his technical review and input into this report; and John Young, RAPID programme director, who provided valuable contributions to the conference and to the publication.

The authors also thank all of the conference speakers and delegates, a full list of whom can be found in the report annexes, as well as all those who attended the event. Finally, they thank Nikki Lee, and Amanda Jones (ODI) and Therese Williams (University of Cambridge) for their excellent editorial, and organisational and administrative support, respectively.

Acronyms and abbreviations

CTBT	Comprehensive Nuclear-Test-Ban Treaty
DSHA	Deterministic seismic hazard assessment
EwF	Earthquakes without Frontiers, UK
GPS	Global Positioning System
InSAR	Interferometric Synthetic Aperture Radar
KNDC	Kazakhstan National Data Center
Mw	Moment magnitude (the best, preferred magnitude scale of earthquake size)
M	Magnitude (using other different scales) of an earthquake, related to Richter's original definition
NSET	National Society for Earthquake Technology, Nepal
ODI	Overseas Development Institute, UK
PGA	Peak ground acceleration
PSHA	Probabilistic seismic hazard assessment
RAPID	Research and Policy in Development Programme, ODI

1 Introduction

Earthquakes kill people and have huge economic costs. More than 500,000 people have lost their lives due to earthquakes in the last decade alone. Approximately two thirds of those deaths occurred in the continental interiors, where there are thousands of active faults that could cause an earthquake at any time. This is particularly true of Central Asia and the Tien Shan region. Despite relatively few destructive earthquakes in recent times, numerous faults mean that earthquake hazard in the region remains high. Historical records show that significant earthquakes in the region have killed large numbers of people. With populations rising, when – not if – the next earthquake occurs, many more people will die.

'Earthquakes don't respect political borders' – James Jackson

Science is key to understanding earthquake hazard, and to reducing damage and loss of life. It was not until the 1960s that scientists could prove that the seismic waves from earthquakes are caused by slip on faults. Today, modern earthquake science in Central Asia seeks to understand and characterise these active faults. With this knowledge, we can create hazard maps to estimate the probability of an earthquake producing a particular level of ground shaking in a particular period of time, and then take steps to mitigate the associated risk. The techniques and tools available to do this have progressed, and countries across Central Asia are investing in new technologies that simply did not exist 20 years ago.

Earthquakes don't respect political borders, and an earthquake can be felt many miles away from the fault that caused it. The damage to Almaty in the 1911 earthquake was caused by movement on a fault at least 50 km away, in Kyrgyzstan. Moreover, because earthquakes occur infrequently in any one country, collaboration between scientists across the region is important to advance our learning. Sharing data and knowledge is critical to understanding the risk and, ultimately, to making populations in the Tien Shan region safer. The Earthquakes without Frontiers (EwF) partnership provides an important opportunity for Kazakh scientists to benefit from mutual learning and collaboration with researchers in other countries.

One of the biggest risks in an earthquake is damage caused by buildings and other structures collapsing. Appropriate building codes, if observed, can greatly reduce the damage. However, earthquake science must be communicated to those with the power to act. Government officials and the public need to be educated about the earthquake hazard and in how to mitigate the risk. This is particularly challenging in Kazakhstan, where there has been no major earthquake in living memory and public awareness is low.

This report is the result of a three-day conference on earthquake science and hazard in Central Asia. The conference was sponsored by the Shakhmardan Yessenov Foundation, which has a long tradition of encouraging geological development and education in Kazakhstan. It was co-hosted by the Kazakhstan Institute of Seismology of the Academy of Sciences, the National Technical University of Kazakhstan, and EwF, a transdisciplinary partnership to improve earthquake science and risk reduction through the exchange of knowledge, information, techniques and data.

Structure of this report

Chapter 2 introduces earthquakes and what we know about the hazard in Central Asia and the Tien Shan region. It outlines what modern earthquake science in Central Asia looks like, drawing on current research in Kazakhstan, Kyrgyzstan, Iran and Italy. Chapter 3 deals with how to make use of this science. It draws on experiences from countries across the continental interiors to explore shared challenges and approaches to communicating earthquake science and turning it into action to mitigate the risk. Chapter 4 presents the key conclusions from the conference, with specific relevance to Kazakhstan.

2 Earthquake science

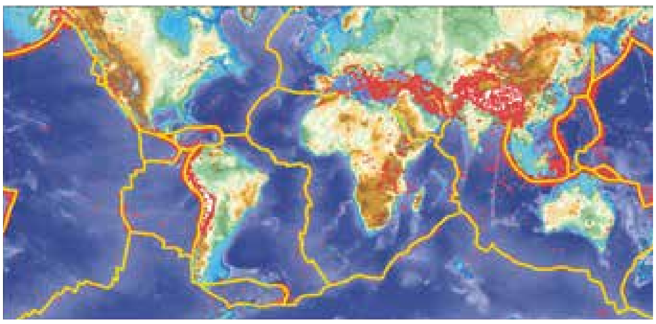
2.1 Introduction to earthquakes in Central Asia and the Tien Shan

Earthquakes happen because the dozen or so tectonic plates that make up the Earth's surface are in constant motion. The movement responsible for earthquakes in Central Asia is that of the Indian continent moving northwards towards Siberia at 40-50 millimetres per year, crumpling up the regions in between and forming mountains. This movement began about 50 million years ago and around half of it takes place in the Tien Shan region.

As the Earth's plates move against each other, friction causes the rocks to bend, building up potential energy known as elastic strain. When this energy becomes great enough, it overcomes the friction, and the rocks break and slip past each other on fracture surfaces known as 'faults'. This sends energy – seismic waves – through the surrounding rocks and to the Earth's surface, which we experience as an earthquake.

The *magnitude* (see 'Definitions' box) of any earthquake depends on the area of the fault surface, and how much it moves (known as 'slip'); the longer and deeper the fault the larger the potential earthquake can be. Faults can be hundreds of kilometres long – causing great earthquakes like the Sumatra earthquake of 2004 in the Indian Ocean – while the smallest earthquakes we can feel may occur on faults of only a few square metres in area. Earthquake rupture usually starts at the base of the fault, which is typically 15-20 km below ground on continents. But in parts of the Tien Shan and its adjacent forelands, faults extend as deep as 45 km, with potentially bigger slip areas and so greater earthquake magnitudes.

Figure 1. Earthquake fault map



In the oceans, earthquakes (red dots) are restricted to narrow bands along the plate boundaries (in yellow). But the situation is different in Asia, where earthquakes reveal thousands of active faults that could produce an earthquake at any given time. Source: James Jackson, 2016.

Definitions

The magnitude (M) of an earthquake is a quantitative measurement of its size, related to the size of the fault that moved, and involves a number between 1 and 10. The original magnitude scale was invented in the 1930s by Charles Richter. It is logarithmic in energy, with each unit being an increase by a factor of about 30: so M5 is about 30 times bigger than M4.

The intensity of an earthquake is a non-quantitative estimate of the local ground shaking at a particular place. It is also expressed as a number between 0 (where nobody felt it) to 10 (where everything is destroyed). Intensity is not a measure of the size of the earthquake, as a house can be destroyed by a small earthquake nearby or by a large earthquake farther away.

Hazard is statement of the threat (e.g. an earthquake of magnitude 6). It describes a physical phenomenon caused by an earthquake – usually ground shaking, ground failure or soil liquefaction.

In any particular place, the *intensity* of the ground shaking normally depends on the magnitude of the earthquake and the distance from it (see 'Definitions' box). It is also affected by the properties of the rocks through which the seismic waves pass. The upper, cooler and stronger layer of the Earth that forms the tectonic plates is called the lithosphere. The thickness of this lithosphere, and the properties of the rocks within it, can vary considerably on the continents. In flat, old geological regions, like central Kazakhstan and India, the lithosphere is often thicker than in younger geological areas, and is better at transmitting vibrations. In these places, an earthquake can produce much greater shaking than one of the same magnitude in nearby mountains, as demonstrated by the 2001 Gujarat (Bhuj) earthquake in India. The flat steppe of Kazakhstan adjacent to the Tien Shan can also host similarly rare and large earthquakes, which are likely to be particularly destructive for the same reason. Therefore, the ability to map these variations in lithosphere properties is an important aspect of good earthquake hazard assessment (see Chapter 2: Earthquake hazard assessments).

When an earthquake occurs on a large fault, the rock may move by up to several metres – vertically and/or horizontally. As earthquakes recur again and again on the same faults, these movements create permanent 'offsets', which accumulate and may be of several kilometres or more. These offsets shape the landscape around us; geographical features such as mountains, basins and high plateaus are all formed by offsets over millions of years. If we understand how these faults work, we can learn to read the signals in the landscape that tell us about the earthquake hazard in a region. For this reason, active faults are a central focus of modern earthquake science.

2.2 The challenge of understanding intracontinental earthquake hazard

We know that earthquakes take place on faults. In the oceans, earthquakes are restricted to narrow zones, often on single faults, which form the boundaries of the Earth's plates and are easily defined. By contrast, within continents – including the Central Asia region – earthquakes are distributed over hundreds of kilometres, on complex networks of thousands of faults that each move less frequently. Identifying these faults and understanding the seismic hazard is therefore much more difficult.

On the continents, repeated earthquakes on the same fault may be separated by thousands of years. In Bam, Iran, prior to the 2003 earthquake, there was no literary or archaeological evidence for any significant earthquakes during the previous 2,000 years. In Kazakhstan, the last major earthquake – which destroyed most of Almaty – happened more than 100 years ago, in 1911.

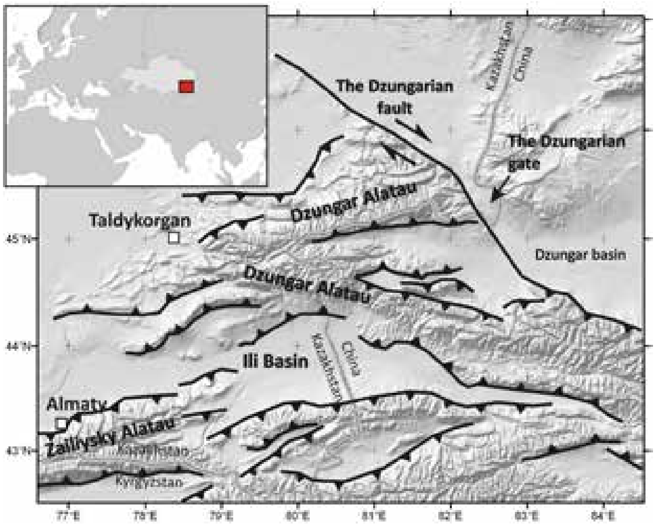
The absence of earthquakes in living memory often leads to the mistaken assumption that a region is not affected by earthquakes. However, as these examples show, in both Iran and the Tien Shan region – and across Central Asia – earthquake hazard remains significant because of the thousands of active faults in the region that could produce an earthquake at any given time.

Many of the recent devastating earthquakes in the continental interiors have taken place on previously unknown faults, either due to lack of research or because their expression in the landscape is subtle or hidden. Some faults never reach the Earth's surface, especially in regions where convergent motion is creating mountains, making it difficult to detect and investigate. An example may be the mountain-front fault thought to be responsible for the 1887 Verney (Almaty) earthquake (M7.3).

Nor are big earthquakes always on major faults that are obvious in the landscape. The 1889 Chilik earthquake in Kazakhstan was probably on a fault that was almost invisible beforehand, and had not moved in the previous few thousand years. With many such faults, it is very difficult to anticipate which are most likely to produce a big earthquake. Moreover, an earthquake can cause destruction tens of kilometres from the fault that caused it (see Box 1: Chon-Kemin, 1911). Investigating faults must take place over large geographical regions to assess hazard properly.

Important additional hazards in the Tien Shan are earthquake-induced landslides and rock-falls, which are common in steep mountainous regions and can cause many casualties and much destruction. Failures of steep slopes and river banks contributed to loss of life and damage in the 1887 Verney earthquake, while a massive landslide blocked the Murghab River in Tajikistan in the 1911 Sarez earthquake of moment magnitude (Mw)[1] 7.7, creating a large lake that still exists today and which will cause catastrophic flooding downstream if the landslide dam fails.

Figure 2. Map of large, known and active faults in Kazakhstan



Source: Richard Walker, 2016.

1 Moment magnitude (Mw) is the fundamental measure of the size of an earthquake. It depends on the area of the fault plane that slipped, multiplied by the amount of the slip, and can be calculated directly from recorded seismograms. Since it was defined in the late 1970s, it has been the routine calculation for all earthquakes greater than a magnitude (Mw) of about 5.5. It is now preferred to the original measurement of magnitude (M) proposed by Richter, which had a less precise physical basis, though the two values are often similar.

Box 1. The Almaty (Chon-Kemin) earthquake, 1911

The last major earthquake to affect Almaty, Kazakhstan's largest city, happened at 04:26 on the morning of 3 January 1911. During the earthquake, almost every building in Almaty was destroyed. The earthquake triggered a number of landslides, which were responsible for many of the lives lost and the damage caused. A total of 452 people were killed and another 740 people injured (Abdrakhmatov et al., 2002). More than 600 houses were completely destroyed, along with 3,000 business premises, warehouses and other non-residential buildings, and 300 homes suffered damage to their foundations, furnaces and plasterwork (Nurmagambetov, 1999). In the city, local ground-shaking intensity was measured as extremely strong, at 9-10. Analysis of original seismograms shows that the moment magnitude of this earthquake was about Mw 8.0 (Kulikova and Krüger, 2015).

'What happens 100 km away is relevant for Almaty' – Richard Walker

Almaty, 1911.

The earthquake caused a complex system of ruptures in the ground in Almaty (see image), some of which were up to 1 m wide, and 5 m deep. These were not the cause of the earthquake, but a response of the frozen unstable soil of Almaty to shaking in the earthquake. In fact, the fault responsible for this earthquake was 145-200 km long and located in the Chon-Kemin valley in Kyrgyzstan, tens of kilometres south-east of Almaty (Bogdanovich et al., 1914), demonstrating that the origin of the hazard to Almaty is not restricted to within Almaty itself.

2.3 Modern earthquake science in the Tien Shan

Identifying and characterising active faults

Work has already been done to map and understand the active, earthquake-generating faults in Central Asia. But more work and collaboration across the region is needed to achieve a picture of the hazard that is as complete as it is, for example, in Italy or California.

Modern earthquake science in the Tien Shan uses a range of methods and data to identify and characterise the faults, including historic records, satellite imagery, geomorphological and geological fieldwork, GPS, InSAR and seismological studies. Taken together, this science helps to build up a picture of earthquake potential and to evaluate the hazard faced by populations living in the region.

Our understanding of seismic hazard – that is, the probability of occurrence and the characteristics of future earthquakes – relies on our understanding of earthquakes that have happened in the past. This allows us to greatly extend our modern data set; we can't gather information from future earthquakes so we need to go back into the past. More information about past events gives us a better and more complete understanding of the earthquake hazards we face, and means we can be better prepared for future events.

Documented accounts of historical earthquakes are particularly helpful. These are used to produce catalogues that supplement the lists and detail we can obtain from analysis of earthquakes seismograms since the start of the modern instrumental period, around 1900. Countries like China, Iran and Italy have rich documented historical records of earthquakes, but they are far from complete – war, invasion, movement of populations and changes to trade routes mean there are periods with no information. In the northern and eastern Tien Shan regions, recorded information is sparse due to nomadic populations. Even the best and most carefully researched historical and modern earthquake catalogues can never fully represent the distribution of hazard, as they span a time period that is short compared to the typical interval between destructive earthquakes on the same fault, which might be thousands of years.

'To understand earthquakes, we need to collect puzzle pieces. Some puzzle pieces come from historic records, some from old instruments – such as analogue seismograms. Others may be looking at the upthrow or downthrow on fault scarps. Taken together, we can build up a better picture.' – Angela Landgraff

Low-altitude photogrammetry survey using helium balloons in Kazakhstan. Photo: Richard Walker, 2015.

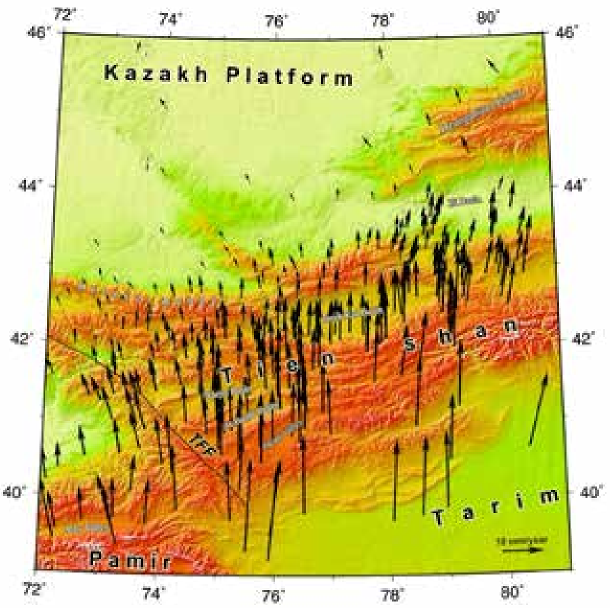
'Through these forensic investigations of individual faults, we are able to build a more complete understanding of the potential for future earthquakes' – Richard Walker

Modern geological and geodetic studies of active faults – including data from paleoseismology – GPS and InSAR, can now provide important complementary information to historical and modern earthquake catalogues. Many of these techniques simply didn't exist 20 years ago, and countries across the continental interiors are investing in them.

Paleoseismology is the study of geological evidence for the past earthquake history on a fault. Typically, it involves digging trenches across known faults, and then characterising and dating sediment layers, or 'strata', in order to detect offsets beneath the ground surface. In suitable locations, and with careful analysis, this information can be used to identify and roughly estimate the date of the most recent earthquakes on the fault, which may be several thousands of years ago. Paleoseismology is particularly well developed in California, Italy, Japan, and northern India, and contributes significantly to our knowledge of earthquake hazard in those regions. In the Tien Shan, important progress is now being made through paleoseismological studies of known faults in Kazakhstan and Kyrgyzstan.

Where large earthquakes occur, the landscape is modified, or even created, by repeated slip on faults. If we understand how these processes work, we can use the signals in the landscape to identify active faults and hazards. The studies of **geomorphology** (how landscape evolves) and **quaternary geology** (that is, over the last 2 million years) have developed dramatically over the last few decades. They help us understand the interactions between earthquake processes, erosion and climate changes, which can all affect the landscape. Clues such as landslides and the deflection or incision of rivers are important and are greatly helped by space or airborne imagery. A particular problem in Central Asia is that large areas are covered by wind-blown dust (called loess), which forms in glacial periods and can accumulate in great thicknesses, especially along mountain fronts. This loess obscures some of the subtler features of the landscape by burying them.

Figure 3. Tien Shan with GPS velocities relative to Eurasia



Source: Zubovich (2010).

Satellite imagery, much of which is now freely available from NASA and other agencies, provides us with useful visuals of the Earth's surface. It can also be used in stereo form to produce high-resolution (to within a metre or better) 3D images of elevation, with which details in the landscape can be investigated. These can often be improved with locally acquired photogrammetric data collected using drones or balloons, or from GPS surveys, to make even higher resolution models of the topography. These in turn can be combined with paleoseismological studies to reveal past earthquake history on a fault (see Box 2: The Lepsy fault).

Global Positioning System (GPS) – the same technology that is used in our smart phones and in car navigation systems – allows us to map the movement of the Earth's surface (see Figure 3) with extraordinary precision: accuracies of 1 mm per year are now routine. Over time, we can calculate the relative speed and direction of this movement over large regions, and see where it is accumulating as bending (elastic strain) near active faults. This is now an important and routine method for identifying important fault systems that can be investigated further by the field-based methods described.

However, it takes time to install GPS networks and to accumulate data; the longer the period of observation, the smaller the errors are in the estimated velocities. For example, Iran has been developing its GPS networks since 1997, and there are now 100 stations covering the entire territory (see Box 3: GPS in Iran). Similar networks are being installed in Central Asia but are generally sparser, and some of the instruments are only temporary, which increases errors in estimated motions. Even with an extensive and well-developed network, GPS measurements are only

Box 2. The Lepsy fault

The Lepsy fault extends over 100 km, from the Dzhungarian Mountains of the northern Tien Shan westwards into the flat-lying Kazakh Platform.

This particular fault is interesting for a number of reasons. It has a large, continuous vertical offset of around 10 m along the scarp, suggesting the occurrence of a large earthquake, or series of earthquakes, in the relatively recent past. The Lepsy fault represents a comparatively poorly understood type of hazard and, from historic documents, no earthquake is known to have happened there. Yet it is a clear example of a kind of fault that poses a particular hazard to the many populous settlements in these flat foreland regions adjacent to mountains in Central Asia, so that if an earthquake were to happen, damage and loss of life could be significant. What's more, smaller, background earthquakes reveal that these faults in flat areas often extend to depths of 45 km, showing their capacity to produce very large magnitude earthquakes like those experienced in northern India.

The study of the Lepsy fault is a good example of where all the techniques described in Chapter 2.3.1 have been used to help understand its earthquake potential (Campbell et al., 2015). We know it has moved in the last 400 years, along a length of about 120 km, with up to 10 m of slip, probably in a single earthquake of Mw 7.5 to 8.2.

Box 3. GPS in Iran

Iran is located within the Alpine-Himalayan mountain belt, one of the most seismically active areas of continental deformation in the world. The country often experiences large and destructive earthquakes. Using GPS, we can see the distribution of the strain building up in mountainous Iran from the convergence between the flat Eurasian and Arabian tectonic plates, which move together at 20-30 mm per year, crumpling the entire country. The political boundaries of Iran correspond almost exactly with the edges of the mountainous and earthquake-prone regions.

To better evaluate seismic hazard, since 1997 Iran has developed GPS networks across the country. While these networks cover all of Iran, they are particularly focused near large cities like Tehran (with a population of around 10 million), Tabriz (2.5 million) and Mashhad (3 million), all of which have suffered large earthquakes in the past. Supported by the National Cartography Center in Tehran, Iran has been working with many different countries, sharing data and experience. But there are still gaps, and GPS data from neighbouring countries would significantly improve understanding of seismic hazard in the region.

made at a single point, so there are still gaps. In favourable circumstances, to fill in these gaps, InSAR is sometimes used.

InSAR (Interferometric Synthetic Aperture Radar) is a space-based radar technique for measuring ground displacement at the Earth's surface between repeated orbits of a satellite. A single InSAR image covers a much bigger area – typically 100x100 km^2 – than GPS, which is a measurement at a single point. However, it has less resolution, measuring changes to within a centimetre or two, rather than one millimetre, as with GPS. InSAR is particularly useful for quickly mapping the ground movement after large earthquakes. Over longer periods, it can monitor strain build-up near faults between earthquakes, particularly when it is combined with a few more accurate measurements from GPS. It works best in dry regions where the ground surface is undisturbed by agriculture, water run-off or slope movement; the deserts of Central Asia and Iran are ideal.

Box 4. Seismic monitoring in Kazakhstan

Seismic stations have been operating in Central Asia since the beginning of the instrumental era, and Kazakhstan has an excellent seismic monitoring network. Before 1996, seismic monitoring across Central Asia developed sporadically, usually with a burst of installations of new instruments following large, destructive and fatal earthquakes. Monitoring stations were established only near to already-identified sources of potential earthquakes. In Kazakhstan, this left more than 80% of the country with no coverage.

But after Kazakhstan's signing of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in 1996, the network was upgraded and enhanced systematically to the highest standards, as part of the international effort to monitor compliance with this historic agreement. Seismometers are now installed throughout the country – in the most active earthquake areas in the south and south-east, but also within the almost earthquake-free regions of northern and western Kazakhstan. The system now includes high-quality seismic arrays across the territory,[i] and can detect all events within it that are larger than magnitude 3.5. The modern Kazakh network records events, not only in Kazakhstan, but across the whole Central Asia region. Each seismic station operates 24-hours a day, and many transfer real-time data to different data centres around the world as part of the global collaboration in seismic monitoring.

[i] *Seismic arrays are linked seismometers arranged in a regular geometric pattern.*

All of these methods have their limitations, but used together they can help to build up a picture of past earthquakes, and therefore future hazard. The Lepsy fault in the Tien Shan region is one example of where several different methods of investigation have been used to learn more about the likely scale and characteristics of an earthquake occurring on the fault in the future.

Realistic assessment of earthquake hazard requires significant effort and investigation. This not only takes time, as shown by the development of Iran's GPS network, but also requires the training of a skilled workforce that is well-informed of modern technical capabilities and well-connected to the international community, where ideas and techniques are constantly being advanced and improved. In India, part government-funded scholarships and long-term partnerships with scientists across the globe have helped to significantly improve the country's capacity for earthquake research. Supriyo Mitra, of the Indian Institute of Science Education and Research Kolkata, sees this as just one critical step in how countries should approach seismic hazard:

- Step 1. Recognise that earthquakes pose a major threat.
- Step 2. Understand that to study earthquakes and quantify the associated hazard requires serious scientific work and commitment over a significant period.
- Step 3. Undertake seismological, geodetic, geological and paleoseismological experiments to acquire data, and encourage cooperation in data and knowledge sharing.
- Step 4. Develop a scientific workforce to study earthquakes, and encourage collaborative efforts with countries that possess significant capability.
- Step 5. Devise mechanisms to educate people about earthquake preparedness and resilience.

'I'm afraid that in a few years, [Kazakhstan] will be without any specialists' – Alkuat Nurmagambetov

Shakhmardan Yessenov[2] made a significant contribution to geology as a field, and to systematised geological studies in Kazakhstan. Importantly, he recognised the need to develop the capacity of the country's young scientists, and sent a number of students to Moscow for training. The development of young scientists must be a continual priority, a sentiment stressed by now retired Professor of Seismology, Alkuat Nurmagambetov, who was among those Kazakh students trained in Russia half a century ago.

2 Who gave his name to the foundation that supported the conference from which this report is written.

Earthquake hazard assessments

The previous sections have focused on the physical properties of the earthquakes and the active faults that produce them. But engineers, architects and planners generally require something more specific to design their structures and infrastructure (including emergency plans) to be resilient to earthquakes. In particular, they need some estimate of likely ground motion or shaking at a particular place like a hospital or a school. This is usually expressed as maximum ground acceleration (peak ground acceleration, or PGA), which is what produces the forces that destroy buildings.

Hazard assessments bring together knowledge from all the modern earthquake science techniques described in the previous sections to develop a picture of the likely distribution, size, character and frequency of occurrence of earthquakes. This picture can be very localised – to a particular active fault, or a place of particular interest – or it can be quite general, across a wide region. Its aim is to make a statement on the nature of the threat, not what can be done about it; nonetheless, it is the necessary first step for developing disaster-risk-reduction policies and strategies, and provides information needed by engineers, architects and planners.

Ilaria Mosca presenting on probabilistic seismic hazard assessment. Photo: Victor Magdeyev/Shakhmardan Yessenov Foundation, 2016.

There are two main approaches to assessing seismic hazard in terms of PGA – deterministic and probabilistic – both of which are used in Kazakhstan.

Deterministic Seismic Hazard Assessment (DSHA) involves the creation of a scenario or model based on the specified properties of an earthquake on a particular fault. To undertake a DSHA, scientists need to specify the location of the fault, the ground or soil properties at the site being studied and its distance from the fault, the magnitude of the earthquake, the amount and direction of fault slip and how well the seismic waves are transmitted from the fault to place of interest (i.e. the properties of the Earth's lithosphere along the transmission path). If scientists know, or can estimate, all these things (hopefully with estimates of uncertainty), they can put likely limits or ranges on the probable PGA at the sites of interest. This is a useful and important exercise when there is a known threat. Examples would be to estimate the PGA within Almaty if there were to be a repeat of the 1911 Chon-Kemin earthquake today, or at a nuclear power station if there was a known active fault nearby.

Probabilistic Seismic Hazard Assessment (PSHA) recognises that our knowledge is never complete. We never know where *all* the active faults are, so can never produce DSHA models for *all* the threats to a particular location. PSHA uses statistical and historical data on earthquake occurrence, and information from known faults in the region, to produce a statement of *probability* of ground motions at a site exceeding a particular PGA in a specific time interval. This may take the form: 'the likelihood of ground acceleration exceeding 0.1 g (10% of gravity) in the next 50 years is 20%'. It does not attempt to specify exactly *where* that earthquake will be, or how *big* it will be, or *when* it will occur.

3 Making use of the science

'[Kazakhstan's] ultimate goal is to be invulnerable to earthquakes; therefore, the planning and implementation of preventative measures should be carried out continuously and not just occasionally' – Alkuat Nurmagambetov

3.1. Understanding the risk

As discussed in Chapter 2, seismic hazard is the potential for dangerous earthquake-related phenomena. If there is sufficient information, the hazard may be expressed as a probability of one of these phenomena occurring. Vulnerability is the degree of potential damage to, or loss of, certain elements, given a particular magnitude of earthquake. Therefore, we can characterise earthquake ***risk*** (R) as a multiplication of ***hazard*** (H) and ***vulnerability*** (V): R = H x V. By estimating the hazard, earthquake science is the fundamental starting point for understanding and mitigating this risk.

Vulnerability depends on what factors are being looked at – for instance, buildings, ecology and environment, economy, infrastructure and human life, among others. In big cities in particular, vulnerability of the population is often the main concern. Over centuries, human settlements have grown up along or in close proximity to natural geographical features and boundaries – features we now know are caused by active faults. This means that there are millions of people living in areas of high seismic hazard.

In Central Asia, populations have developed along trade routes that mostly follow mountain ranges. Similarly, in Bam, Iran, where the surrounding area is mostly desert, the city grew up near to active faults because of the water that these faults trap underground. Over time, these populations have grown from relatively small communities of thousands of people into cities with populations of millions, meaning more and more people are at risk.

The seismic hazard cannot be reduced or controlled. Nor can we say – in the short term – when, where or how a seismic event will occur (see Box 5: Long- and short-term forecasting). Hazard is a feature of the natural world. We cannot mitigate or reduce hazard, but we can reduce risk by understanding and reducing vulnerability.

Box 5. Long- and short-term forecasting

Short-term forecasting means predicting the precise time at which any earthquake will occur, something that the current state of earthquake science is unable to do. However, with appropriate and sustained research, long-term forecasting – that is, identifying the approximate locations of future earthquakes, and forecasting their likely size and character – is increasingly possible. Long-term forecasting enables countries to work towards reducing the risk associated with the hazard, by reducing vulnerability through appropriate educational, social, political and engineering action.

'Long-term forecasting is simply saying that, where there's been an earthquake in the past, there will be another one day. It's not saying when, but it's saying it will happen. And it's saying you can prepare for it.' – James Jackson

3.2. Communicating the risk

Understanding the earthquake risk in a region is only useful if it is communicated to, and understood by, those with the power to act. Seismic hazard assessments (see Chapter 2) can be a powerful tool to communicate danger, and to inform strategies to mitigate the risk. Science can tell us the potential magnitude of an earthquake, the estimated intensity of ground shaking and the likelihood of other physical phenomena. And so, seismic hazard assessments can evaluate the threat for a particular site, such as a building, or for a larger area, such as a city – or even a country.

Conference field trip to Rakhat, Kazakhstan. Photo: Victor Magdeyev/Shakhmardan Yessenov Foundation, 2016.

Box 6. From prediction to preparedness in China

With 35% of all earthquakes in the continental interiors occurring in China, the country has a long history of earthquake research and planning. In 1975, scientists used a series of small earthquakes (later identified as foreshocks) to anticipate the occurrence of a bigger one – the Haicheng earthquake (M7.3).

This apparent success of short-term prediction was short-lived, however; just a year later and without any precursors or foreshocks, the 1976 Tangshan earthquake (M7.8) happened, killing more than 255,000 people. Following this earthquake, believed to have been the deadliest of the 20th century, people's confidence in prediction plummeted (Mei et al., 1993; Zhang et al., 2001).

Since the 1976 Tangshan earthquake, and especially since the 2008 Sichuan earthquake, there has been much greater emphasis on seismic risk mitigation in China, and a move away from short-term prediction research (Chen and Wang, 2010). Many places in Europe, the US, Japan, and South America have moved in the same. direction. The China Earthquake Administration is now clear that their earthquake public-safety policy and response is focused on preparedness and risk mitigation, and not on short-term prediction.

From seismic hazard assessments, we can produce an earthquake damage scenario – an assessment and description of the estimated effects that a future earthquake could have on critical infrastructure in a geographical area. Scenarios translate the science into real-life impact: the number of likely deaths, projected damage to buildings and critical infrastructure, to name but a few. This information can be used by governments, businesses, institutions, communities and individuals to develop earthquake disaster-risk management strategies that reduce vulnerability.

'Risk assessment is not an end goal; it's the starting point for earthquake-risk management' – Surya Shrestha

Take, for example, managing risk from building collapse. Around the world, about 75% of earthquake-related deaths are caused by building collapse (Daniell et al., 2011). Ensuring that buildings and other structures are made to withstand.d the expected intensity of ground shaking in a given location, therefore, is one of the best ways to save lives in the event of an earthquake. A well-designed national building code – that is, a building code informed by earthquake hazard assessment and enforced by government authorities – saves lives.

To reduce risk, hazard needs to be communicated to, and understood by, many different people and stakeholder groups at different levels. For example, in the case of vulnerability of buildings:

- National and local governments are responsible for producing and enforcing an appropriate building code, land zoning regulations, and taking responsibility for assessing and retrofitting existing buildings (see Box 7).
- Engineers and architects need to work with government to develop building codes that are appropriate both to the hazard and to the local context. They are also responsible for developing locally viable solutions, such as using affordable and local building materials.
- Civil society, professional associations, private companies and government bodies need to provide training to construction workers in how to apply the building codes and explain why they are important. Construction workers need to put the building codes into practice, both in new buildings and in retrofitting existing buildings (see Box 7).

The actors and processes involved in reducing earthquake vulnerability are context-dependant, and it is vital to engage the right people in the right way. In Nepal, the National Society for Earthquake Technology (NSET) has supported the government in developing new building codes, and has successfully trained engineers and construction companies. However, 93% of buildings in Nepal are not produced by engineers or formal construction companies, but rather informal-sector local masons, who are often also the occupants. NSET is therefore in the process of creating separate, specific guidance for informal-sector masons. Similarly, in Bam, Iran, earthquake scientists realised that they needed to communicate hazard directly to construction workers, who are often only informally trained. Instead of distributing a complex building code, they developed a short, easy-to-understand construction guide with illustrations.

'Earthquakes don't kill people; buildings do' – Nick Ambraseys (1968)

Yet engagement doesn't begin and end with those involved in legislation and regulation – individuals and communities also need to understand earthquake hazard. There is a moral imperative, first and foremost, to make the public aware of the risk to their safety and their home; and second, individuals and communities can also take action to reduce their vulnerability. If they are able, they may choose to invest in strengthening or building more resilient homes. They can also be a powerful force in demanding the government do more to regulate the construction industry. The experience in countries like Chile is that if the public demands that politicians prioritise earthquake safety, those politicians will do so.

3.3. Political will and policy

Governments are ultimately responsible for public safety – and they are not only responsible for what they do, but for what they don't do. Governments are responsible for developing strong infrastructure, and implementing and enforcing building codes and risk-reduction strategies *before* an earthquake hits.

This approach can be seen in China, where the government leads a top-down approach to earthquake disaster risk reduction through public policy. In 2008 the Chinese government passed the Law on Protecting Against and Mitigating Earthquake Disasters, a strong, top-down approach combining preventative measures and rescue efforts.

For governments to implement good disaster-risk-reduction policies, decision-makers need to understand the nature of the risk. Seismic hazard maps can be used to communicate earthquake risk to governments (see Chapter 2.3.2), but it is not always enough to make information available – sometimes you have to *convince* people.

The challenge of convincing governments to act is that they are faced with many competing priorities, such as poverty, pollution, traffic and unemployment, to name just a few. This is often compounded by the fact that, despite high earthquake hazard, in many countries – including Kazakhstan – there has not been a significant earthquake in living memory. Therefore, both residents and politicians have limited awareness and understanding of what the

Box 7. Retrofitting to reduce risk

Retrofitting buildings that pre-date building codes, or where the codes have not been enforced, remains a significant challenge and a priority for many governments. Italy, for example (like many other Mediterranean countries) is characterised by a valuable ancient building heritage that cannot simply be replaced but must be retrofitted. But, despite a very good level of scientific awareness of the hazard and how to mitigate the risk, the level of retrofitting is still low and the quality often poor. In Italy, therefore, increasing building resilience is a priority.

In Nepal, NSET has been working with local governments, engineers and communities to find retrofitting solutions that are technically feasible, economically affordable, culturally appropriate and locally capable. And long-term investment in retrofitting has paid off: they have now retrofitted more than 300 buildings in Kathmandu, including schools as part of the School Earthquake Safety Programme. All survived the recent 2015 earthquake, whereas more than 7,000 other schools (80% of those exposed) were damaged or destroyed. An additional benefit was that people could live in these retrofitted school buildings after the earthquake, without fear of damage in aftershocks. The Nepalese government is continuing the retrofitting programme.

Children checking the seismic properties of toy structure, during disaster risk-reduction classroom activities, China. Photo: Gender Development Solutions.

risk means for them. Furthermore, short-term political cycles mean that politicians concentrate on the more immediate and visible issues. This problem was illustrated by Kanatbek Abdrakhmatov, Director of the Institute of Seismology in Bishkek and Associate of the Institute of Seismology in Almaty:

> *'In Kyrgyzstan the earthquake hazard is high. Comprehensive hazard maps have enabled scientists to assess the earthquake risk. Given the current population level and density, an earthquake with intensity 9 in Bishkek could result in more than 90,000 deaths. This is a number, a calculation, but if you translate this into what it means for people's lives, families and communities, it is a terrible loss. Many people in Kyrgyzstan don't understand this possibility. And policy-makers fail to really understand the risk. At one meeting, I was talking about risk and asked attendees to share what they understood by risk. The only answer I got was "The person who doesn't take risks, will never drink champagne". There was no comprehension of what earthquake risk is, what it means, and why it is so important to act.'*

Engaging governments with earthquake risk is hard. Politicians are not necessarily technical experts, and are sometimes therefore not able – or willing – to understand the language of scientists. It is important for scientists to translate the earthquake information into political language, understanding this audience's different priorities and limitations. Research into how policy decisions are made shows that evidence is just one factor in decision-making. Scientific information needs to be communicated in the right way, at the right time (see Chapter 3.5: What is working?).

Moreover, scientists may not always be the best people to communicate research to policy-makers or other stakeholders. Therefore, intermediaries can be very important. In Nepal, which has an active civil society, NSET are playing this role. They have enough understanding of the science, and of the political processes and needs, to be able to communicate it to different stakeholders.

There is always a danger of *mis*-communication and misunderstanding of scientific knowledge, as in the case of the 2009 L'Aquila earthquake in Italy. In this instance, comments made by scientists to the emergency planning committee meeting of the Civil Protection Authority were misinterpreted by policy-makers, and mis-reported by the media. When scientists said that earthquakes are inherently not predictable in the short-term, and that a strong earthquake in the few days following a sequence of small shocks was unlikely but not impossible, what was understood was that an earthquake would *not* happen. When a big earthquake did happen, killing hundreds of people, there was public outcry, followed by a long legal battle over who (if anybody) was responsible for what the public thought was misleading or inadequate information and advice.

'In the 2015 Nepal earthquake, 98% died because of falling buildings. Would prediction have helped? No. Short-term prediction is a luxury. We don't have any right to spend time and money on something that is not saving people; we need to be working to improve living standards and safety.' – Amod Dixit

There is strong appetite among the general public and decision-makers for earthquake scientists and experts to predict earthquakes. However, the current state of earthquake science means such short-term prediction is impossible. Moreover, short-term prediction does not reduce vulnerability to earthquakes; without proactive steps to manage and mitigate the effects of a potential earthquake, when an earthquake occurs there will still be human causalities, damage to infrastructure and vast economic loss. Allowing hope for short-term prediction breeds complacency and inaction, and incorporating such an approach into public-safety policies is dangerous.

Of course, the amount that a government can do depends on resources, and prioritisation of these resources. But earthquakes should be prioritised – they have huge costs and are deadly, and unlike floods or meteorological disasters, which are seasonal, earthquake hazard is there 365 days of the year (Figure 4).

3.4. Public awareness and preparedness

Individuals need to understand earthquake hazard and the risk to them, their families, homes and communities, so that they can prepare and take action to reduce their vulnerability. For example, they may choose to invest in strengthening or building more resilient homes.

Public awareness also plays an important role in increasing a country's overall preparedness, by increasing demand for earthquake risk-reduction strategies and action. For example, people can demand that construction companies build their homes according to appropriate building codes, and communities can take action to ensure that their schools and hospitals are resilient.

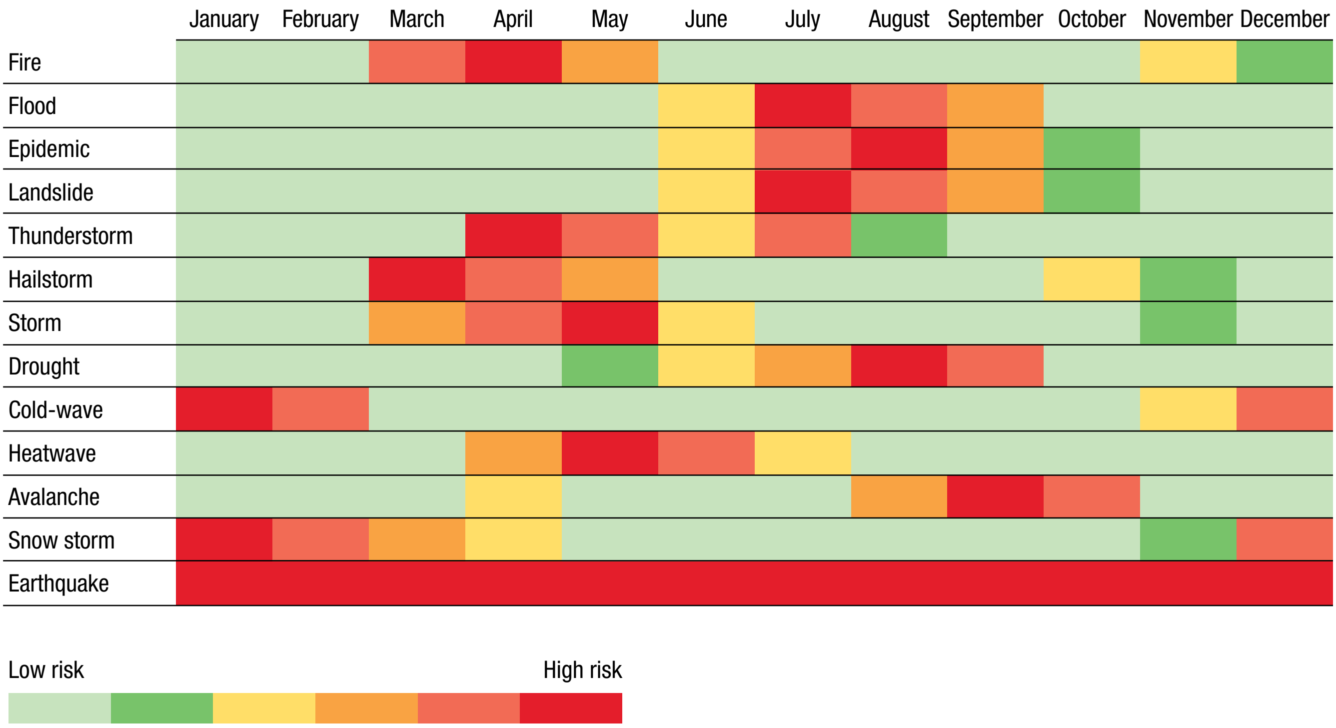
In Nepal, public awareness-raising and community training has paid off in practical and life-saving ways: during the 2015 earthquake, more than 17,000 survivors – 80% of the total rescued – were extracted from buildings and rubble by the community or themselves.

In most of continental Asia, despite the high earthquake hazard, the relative infrequency of earthquakes means that the general public is not always aware of the risk.[3] One of the most common reasons for not informing the general public about earthquake risk is concern that it will cause panic. However, evidence from other countries shows that an informed public actually leads to increased resilience and preparedness. This is for two main reasons. First, if people are informed, they are more emotionally resilient: they understand the risk and have agency to act, which reduces panic and the dependency on state-led responses. Second, on a practical level, with the correct information and preparation, people know what to do in a crisis and can better organise themselves to respond when an earthquake hits.

Ideally, disaster risk-reduction strategies will combine top-down and bottom-up approaches, leading to overall greater resilience and preparedness. In Japan, for example, earthquake awareness and social resilience is high. The 2016 Kumamoto earthquake was followed by a swift and organised state-led evacuation process, moving large numbers of people into temporary accommodation, but people were calm and in control because they were prepared and knew what to expect. Bottom-up approaches to disaster preparedness are therefore important to complement top-down initiatives.

3 In Chile, most people will experience one M5 earthquake every year, one of M7 every 10 years and one of M8+ in their lifetime. For them, earthquake risk is not theoretical.

Figure 4. Mapping the natural hazards faced by Nepal



This figure demonstrates that am earthquake can happen at any time; it has no seasonal variation. Source: Desinventar Database (1971-2014). Graphic reproduced with kind permission from NSET.

Of course, raising public awareness about earthquakes in countries like Japan and Chile, which experience them frequently, is relatively easy; most people will have experienced an earthquake in their lifetime and so know first-hand the risk. In Central Asia, where earthquakes are far less frequent, it is not enough to inform people of the risk; like governments, sometimes the public too will need *convincing*. Individuals and communities have their daily struggles and issues to deal with, and so it is also a question of priorities. In Nepal, for example, NSET found that talking about earthquakes with people who had not experienced one was not helpful. The risk did not feel real, or immediate. They were more concerned with the impact of landslides caused by heavy rainfall, which affected them every year. As landslides are also a major secondary hazard of earthquakes, this has presented a possible route for NSET to engage communities in earthquake risk (see Section 3.5: What is working?).

It is important to translate earthquake hazard assessment into language that non-experts can understand and to take into account the limited choices that many people have. It involves going into communities and speaking with people, as well as training local masons, teachers, students and others.

'If a person has no money, he will build a house with the materials he has now, on the plot of land he has been given, even if he has all the necessary information [about earthquake risk] ...because he has to live; he has a family to provide for. Because that's life: it's snowing, the baby is crying, and he will build his house. There is no ready-made solution. There are a huge number of factors to take into account. The first step is to speak the same language.' – Kanatbek Abdrakhmatov

The NSET shaking table demonstration. Photo: NSET, 2015.

3.5 What is working?

During the conference, the international speakers shared experiences of and ideas for communicating earthquake risk to the general public and to decision-makers to improve preparedness and, ultimately, save lives and livelihoods.

Educating children in earthquake awareness and preparedness

Experience shows that educating young people can be one of the most effective ways to increase public awareness. This is for two reasons: first, children grow up, so informing children of the risk will lead to increased long-term awareness among the general public; second, children will often go home from school and tell their families what they have learned. Experience from conference participants showed that this is working in different contexts. In China there is a saying that 'the little hands hold the big hands'; China has been emphasising child preparedness by targeting schools for raising awareness of disasters and performing drills. In Iran, a 15-minute children's TV programme has also been an effective awareness-raising strategy.

Using scenarios to communicate earthquake risk in real terms

Earthquake damage scenarios are particularly useful for earthquake risk reduction in two ways. First, they are an important planning tool: based on the scientific understanding of the hazard in an area or for a particular site, a scenario can identify the vulnerabilities and risks, taking into account local knowledge and expertise, to develop tailored and practical risk-reduction strategies. Second, they are a powerful awareness raising tool. Damage scenarios translate scientific understanding of hazard and risk into real-life impact – for example, the number of likely deaths and projected damage to buildings and critical infrastructure.

Models and demonstrations have also proved successful in communicating earthquake risk to the general public. In Nepal, the 'NSET Shaking Table' has had a great deal of success. This is a model of two buildings, side-by-side, which, when shaken vigorously, demonstrates the importance of retrofitting (one crumbles, the other remains intact). The model can be particularly useful for children, or less literate groups and, ultimately, represents a simple and convincing way to communicate risk to all stakeholders.

Using a 'multi-hazard' approach to engage people in earthquake risk

In rural communities in Shaanxi Province, China, researchers in the EwF project found that earthquakes often seemed like a distant threat (or that people were even not aware of the threat at all) as there hasn't been an earthquake in the region in living memory. Communities were more concerned with more common disasters such as droughts, fires, floods and landslides. Engaging communities in disaster risk reduction relating to these more prevalent threats presented non-governmental organisations working in the area with a 'way in' to talking about earthquake risk. Furthermore, engaging communities with risk relating to landslides – and helping them to mitigate that risk – will also help to reduce earthquake risk, as landslides are a common secondary earthquake risk in the mountainous rural communities of Shaanxi Province. Findings were similar in rural communities in Nepal, which were also more aware of landslide-related hazards, and in north India where, although a large earthquake caused great damage and loss of life in 1934, regular flooding of the Ganges River remains a more commonly experienced danger.

The immediate time after an earthquake is an important opportunity to engage policy-makers

Countries that have earthquakes most often tend to be more prepared. Governments and people learn from experience. In countries where earthquakes may happen infrequently, it is even more important to learn as much as possible from each earthquake. In addition to testing risk-reduction and response strategies, the immediate time after an earthquake is a key moment when governments are more receptive to addressing earthquakes as a policy priority.

But countries cannot wait for people to die and for cities to be destroyed before tackling earthquakes. Particularly where earthquakes haven't occurred for a number of years, researchers can use the experiences (and often tragic losses) of other countries to engage policy-makers. Earthquake damage scenarios that describe the estimated effects that a future earthquake could have on a city or country can be a powerful way to communicate the risk (see previous section on using scenarios to communicate earthquake risk).

'I often hear "Don't tell people! They'll get panicked", but I'm 68 and I haven't seen that people are so foolish as to get panicked when information is given to them; I've only seen them panic when they feel they've been deceived' – Amod Dixit

Engaging stakeholders using social media

The use of social media as a tool for public engagement is becoming more common, in both urban and rural communities around the world. It is a way to reach large numbers of people, with simple and easily understood messages. In Italy, during an earthquake sequence in 2013 the mayor of Castelnuovo di Garfa sent a tweet advising residents to 'sleep away from home', before evacuating the historic town centre after a warning of possible strong tremors from the Civil Protection authorities (Mitzman, 2013).

Kazakhstan's Institute of Seismology receives a number of requests from the general public to advise them on earthquake hazard when they're looking to build or purchase property. During the conference, Natalya Silacheva from the Kazakhstan Institute of Seismology suggested that a mobile application ('app') that makes this data available and easily accessible could be a good way to engage the public and educate them about earthquake hazard.

Conclusions

The experiences and learning shared during the conference upon which this paper has been based have broad applicability. As summarised in this paper, participants heard about the exciting methods and technologies being used around the world to understand seismic hazard, and about the role of modern science in minimising damage and death when – not *if* – the next earthquake occurs.

In bringing together international experts in earthquake science to share both their different and often similar experiences in earthquake science, and in disaster risk-reduction policy and practice, the conference showed that earthquakes are truly without frontiers, and that collaboration and learning is essential if we are to save lives and livelihoods.

With this in mind, the third day of the conference drew together key messages that had emerged over the three days and considered how they could inform earthquake science, policy and practice in the host country. Wording adapted from the conclusions of a similar meeting in Tabriz hosted by the Geological Survey of Iran in 2014 (GSI Congress, 2014) was used to frame discussions. This was then modified after comments from a panel of international experts including Kazakh delegates, and from international and Kazakh audience members, to produce a series of concluding statements and lessons for Kazakhstan.

Lessons for Kazakhstan

1. **Everywhere within or adjacent to the mountainous parts of South and East Kazakhstan is vulnerable to earthquakes.** Within this mountainous region, a large proportion of the population of Kazakhstan is exposed to earthquakes and their associated hazards, such as landslides and rock-falls, particularly in cities.

2. Earthquakes have caused – and will cause in the future – loss of life, injury, destruction of property, and economic and social disruption. **However, future loss, destruction, and disruption from earthquakes can be substantially reduced** through the development and implementation of mitigation measures.

3. **The current state of earthquake science is unable to predict the precise time at which any earthquake will occur**. However, with appropriate and sustained research, it is increasingly possible to identify the approximate locations of future earthquakes and to forecast their likely size and character, from which an estimate of the level and nature of the hazard can be made. This may include both general and site-specific seismic zoning, and can be considered as a long-term prediction of where earthquakes could occur and how strong they might be. It is then possible to work towards reducing the risk associated with the hazard through appropriate educational, social, political and engineering action.

4. **It is not necessary to predict the precise times of earthquakes to have a dramatic effect in reducing their consequences**. The experience of countries such as Japan, Chile, the US and New Zealand, as well as in the former Soviet Union, shows that this approach, practiced over decades, is effective at increasing resilience to earthquakes and, in particular, at reducing the number of deaths in earthquakes.

5. **Encouraging a hope that science will deliver a reliable method of predicting the times of earthquake is counter-productive**; it encourages the public and officials to do nothing, while hoping that scientists will 'solve' the problem, which they will not do. Instead, the public, officials and scientists need to work together, to take responsibility for what can be done to mitigate the effects of earthquakes.

6. **The experience of several countries shows that appropriate building codes and standards, if observed, can greatly reduce the damage caused by earthquakes.** But the building codes alone are not enough; they need to be enforced for all new buildings and attention needs to be paid to retrofitting existing buildings. While the government should cover the additional cost for public buildings (especially schools and hospitals), private sector companies and the public should be expected to cover the cost of private buildings. Government agencies can help by providing information and training.

7. **Officials and the public need to be educated about the hazard and how to mitigate the risk.** This is particularly challenging in Kazakhstan, where there has been no major earthquake in living memory and awareness is low. Educating children and teachers in schools is particularly important, and has proved an effective method to reach adults in many countries. Open and honest communication and high ethical

standards are vital. Scientists should be encouraged to provide realistic advice to government based on current knowledge. Effective systems should be established between scientists and the government to determine the risk, and should be communicated clearly using appropriate channels to the public, who also have a responsibility for their own safety.

8. **Realistic assessment of earthquake hazard requires work.** In particular, it is necessary to identify active earthquake-generating faults, which may be unknown or hidden. With careful research, their characteristics can be revealed, including their long-term movement rates and the past history of earthquakes on them. This is particularly important in Kazakhstan, where the interval between earthquakes is long and most earthquakes predate modern seismological instruments. **Developing the knowledge and skills of young scientists is essential.**

9. **The origin of the earthquake threat may not be in the same place as the earthquake risk.** The damage to Almaty in 1911 was caused by movement on a fault at least 50 km away. Moreover, this causative fault is located outside the Kazakhstan territory – in Kyrgyzstan. This highlights the fact that **earthquakes do not recognise political boundaries.** A large earthquake can have devastating effects beyond a country's borders. Regional collaboration and joint scientific projects are crucial for proper understanding of the hazard and reducing risk to societies. Continuing the British-Kazakh and Kyrgyz-Kazakh collaborations is essential.

10. **Severe earthquakes are a worldwide problem.** Since damaging earthquakes occur infrequently in any one nation, international cooperation is beneficial for mutual learning from limited experience. The EwF partnership provides an important opportunity for Kazakh scientists to benefit from this shared learning. Demonstrating that they are well-connected to international scientific understanding and opinion can also empower scientists in their respective countries, and give them more authority and credibility when talking to their own politicians, public and decision-makers.

Annex A. Conference programme

Earthquake Science and Hazard in Central Asia Almaty, Kazakhstan, 7-9 September 2016

Day 1. Current earthquake science in Central Asia

Facilitator
Alexander Strom (Moscow)

Presentations
Honourable Deputy Akim of Almaty (Rumil Taufikov), Professor Abakanov, Professor Jackson
Introductions and welcome

James Jackson (Cambridge, UK)
Overview of meeting, aims and central Asia earthquakes

Tanatkan Abakanov (Almaty, Kazakhstan)
Earthquake hazard and risk in Kazakhstan

Richard Walker (Oxford, UK)
Earthquake science in the Tien Shan

Kanatbek Abdrakhmatov (Bishkek, Kyrgyzstan)
Great historical earthquakes in the Tien Shan

Galina Kulikova (Potsdam, Germany)
Seismological studies of major historic earthquakes in the Tien Shan

Natalya Mikhailova (Almaty, Kazkahstan)
Seismic monitoring in Kazakhstan

Christoph Greutzner (Cambridge, UK) and **Grace Campbell** (Arup, UK)
Geomorphology and Quaternary geology of active faults in Kazakhstan and Kyrgyzstan: Chon-Kemin, Chilik and Lepsy

Angela Landgraf (Potsdam, Germany)
Paleoseismological investigation of historical earthquakes in Kazakhstan and Kyrgyzstan

Alex Copley (Cambridge, UK)
Use of InSAR and GPS in studies of active faults

Keith Priestley (Cambridge, UK)
Lithosphere structure of Central Asia and Tien Shan

Natalya Silacheva (Almaty, Kazakhstan) and **Ilaria Mosca** (Edinburgh, UK)
Earthquake hazard assessment in Kazakhstan

Alexander Strom (Moscow, Russia)
Earthquake-induced landslides in the Tien Shan

Day 2. Earthquake hazard evaluation and approaches to risk management

Facilitators
John Young (London, UK) and **Tim Sim** (Hong Kong, China)

Presentations
Alkuat Nurmagambetov (Almaty, Kazakhstan)
Academician Yessenov and seismology in Kazakhstan

Tanatkan Abakanov (Almaty, Kazakhstan)
Earthquake science and policy in Kazakhstan

Kanatbek Abdrakhmatov (Bishkek, Kyrgyzstan)
Earthquake risk reduction in Kyrgyzstan

Nicola D'Agostino (Roma, Italy)
Earthquake hazard estimation in Italy

Zahra Mousavi (Zanjan, Iran)
GPS and earthquake hazard in Iran

Morteza Talebian (Tehran, Iran)
Earthquake science and risk reduction in Iran

Grace Campbell (Arup, UK)
Lessons from the 2016 Kumomoto earthquake in Japan

Supriyo Mitra (Kolkata, India)
Earthquake hazard in India and the Himalaya

Amod Dixit (Kathmandu, Nepal)
Lessons from two decades of preparing for earthquakes in Nepal

Tim Sim (Hong Kong, China)
Reflections on earthquake science and policy in China

John Young (London, UK)
Science into policy: an international perspective

Natalya Mikhailova, Director of Kazakhstan National Data Center, presenting on seismic monitoring in Kazakhstan. Photo: Victor Magdeyev/ Shakhmardan Yessenov Foundation, 2016.

Day 3. Earthquake risk: perceptions, policy and education

Facilitators
Amod Dixit (Kathmandu, Nepal) and **James Jackson** (Cambridge, UK)

Session 1: Lessons from some recent earthquakes in the Mediterranean-Asian earthquake belt

Presentations
Nicola D'Agostino (Rome, Italy)
The 2009 L'Aquila earthquake in Italy

Surya Shrestha (Kathmandu, Nepal)
The 2015 Gorkha (Nepal) earthquake

Morteza Talebian (Tehran, Iran)
The 2003 Bam earthquake in Iran

Kanatbek Abdrakhmatov (Bishkek, Kyrgyzstan)
The 2008 Nura earthquake in Kazakhstan

Tim Sim (Hong Kong, China)
The 2008 Wenchuan earthquake in China

Session 2: How to benefit from the experience, knowledge and understanding of different countries

Moderator
Chokan Laumulin (Almaty, Kazakhstan) and **Susanne Sargeant** (Edinburgh, UK).

Panel
Tanatkan Abakanov (Almaty, Kazakhstan)

Kanatbek Abdrakhmatov (Bishkek, Kyrgyzstan)

Nicola D'Agostino (Roma, Italy)

Morteza Talebian (Tehran, Iran)

Surya Shrestha (Kathmandu, Nepal)

Supriyo Mitra (Kolkata, India)

Tim Sim (Hong Kong, China)

Questions

- What general or generic lessons can be learned from the earthquake case histories in different countries?
- What are the most effective ways to raise awareness and help prioritise earthquake mitigation measures with the public, and with policy, and decision-makers?
- How can scientists, the public and decision-makers work together and help each other?

Session 3: Focus on Kazakhstan

Moderators
Chokan Laumulin and **John Young** (London, UK).

Panel
Tanatkan Abakanov (Almaty, Kazakhstan)

Alkuat Nurmagambetov (Almaty, Kazakhstan)

Kanatbek Abdrakhmatov (Bishkek, Kyrgyzstan)

Alexander Strom (Moscow, Russia)

Amod Dixit (Kathmandu, Nepal)

Questions

- What lessons have emerged from the meeting that might be relevant to Kazakhstan?
- How could these lessons be taken forward?
- How can an international partnership like EwF help with this in Kazakhstan?
- What general conclusions can be drawn?

Annex B. Conference participants

Delegates from Kazakhstan

Dr Tanatkan Abakanov (Institute of Seismology, Almaty)
President of the National Center for Seismological Observation and Research, Director of the Institute of Seismology, Doctor of Technical Sciences, Academician, UNESCO consultant on seismology and earthquake engineering.

Dr Natalya Mikhailova (KNDC, Almaty)
Director of Kazakhstan National Data Center (http://www.kndc.kz). Earthquake Seismologist working within the International Monitoring System (IMS) for verification of compliance with the Comprehensive Nuclear-Test-Ban treaty (CTBT).

Dr Alkuat Nurmagambetov (KazNRTU named after K. Satpayev, Almaty) Professor of Seismology. Experienced seismologist working in field of seismic-hazard assessment, technogenic seismic phenomena associated with the development of mineral resources, increasing seismic literacy.

Dr Natalya Silacheva (Institute of Seismology, Almaty)
Seismologist specialising in seismic hazard assessment, microzonation, engineering seismology

Delegates from the UK

Ms Louise Ball (Overseas Development Institute – ODI, London)
Senior Communications Officer for the Research and Policy in Development (RAPID) programme at ODI. Expertise in not-for-profit communications, including strategic development, research uptake, publication management and digital communications.

Dr Greg Bankoff (Department of History, University of Hull)
Professor of Environmental History. Interested in adaptations to risk and disaster governance in Asia, Australasia and Europe. Field-based projects in Kazakhstan and the Philippines.

Ms Hannah Caddick (Overseas Development Institute – ODI, London)
Communications Officer for the Research and Policy in Development (RAPID) programme at ODI. Expertise in not-for-profit editorial and communications across digital and print, publication project management, and layout and design.

Dr Grace Campbell (Arup consulting engineers, London)
Earthquake geologist with field experience of active fault investigations in Kazakhstan and Kyrgyzstan.

Dr Alex Copley (Department of Earth Sciences, University of Cambridge)
Geologist and geophysicist with interests in active tectonics and geodynamics, using geodesy, seismology, geomorphology and numerical modelling. Field experience in Greece, Iran and India.

Dr Austin Elliott (Department of Earth Sciences, University of Oxford)
Earthquake geologist, with interests in geomorphology and paleoseismology. Field experience in China, Kazakhstan and US.

Dr Christoph Gruetzner (Department of Earth Sciences, University of Cambridge)
Earthquake geologist, with interests in geomorphology and paleoseismology. Field experience in Greece, Spain, Germany, Oman, Kyrgyzstan and Kazakhstan.

Dr James Jackson (Department of Earth Sciences, University of Cambridge)
Professor of Active Tectonics. Leader of Earthquakes without Frontiers. Earthquake geologist and seismologist, with field experience throughout the Mediterranean, Middle East and Asia, and also in Africa, the US and New Zealand.

Mr Chokan Laumulin (Centre for Development Studies, University of Cambridge)
Research Fellow of Cambridge Central Asia Forum. Journalist, author, historian and researcher of technological development in the Soviet Union and the post-Soviet Eurasia.

Dr David Milledge (Department of Geography, University of Durham)
Geomorphologist interested in erosion, landslides and natural hazards in mountains. Field experience in Nepal and Kazakhstan.

Dr Tanatkan Abakanov, Institute of Seismology, Almaty. Photo: Victor Magdeyev/Shakhmardan Yessenov Foundation, 2016.

Dr Ilaria Mosca (British Geological Survey, Edinburgh)
Seismologist specialising in seismic hazard assessment, with collaboration in Kazakhstan.

Dr Katie Oven (Department of Geography, University of Durham)
Geographer working on the vulnerability and resilience of communities to natural hazards and on disaster risk reduction. Field-based projects in Nepal, India (Bihar State), Kazakhstan and China.

Dr Keith Priestley (Department of Earth Sciences, University of Cambridge)
Professor of Seismology. Uses earthquakes to investigate the internal structure of the Earth and for tectonic and geodynamic studies. Extensive experience of running seismometer networks in the US, Chile, Iceland, Mediterranean, Iran, India, Kazakhstan, Turkmenistan, Azerbaijan and New Zealand.

Dr Susanne Sargeant (British Geological Survey, Edinburgh)
Seismologist specialising in seismic hazard assessment, with collaboration in Kazakhstan. Also interested in public education, science communication and policy, especially with international organisations.

Dr Montu Saxena (Department of Physics, University of Cambridge)
Solid-state physicist and Chair of Cambridge Central Asia Forum, which aims to promote and facilitate a wide range of collaborative scientific, social science and development research programmes across Central Asia.

Dr Peter Sammonds (Department of Earth Sciences, University College London)
Professor of Geophysics and Director of the Institute for Risk and Disaster Reduction. Specialist in the physics and mechanics of geological materials, and researcher into the impacts of climate change and natural hazards.

Dr Richard Walker (Department of Earth Sciences, University of Oxford)
Professor of Tectonics. Earthquake geologist using remote sensing and field investigations to investigate the earthquake history of active faults. Extensive field experience in Mongolia, Iran, Tibet, Taiwan, Greece, Morocco, Kyrgyzstan, Kazakhstan and China.

Dr John Young (Overseas Development Institute – ODI, London)
Head of the Research and Policy in Development Programme (RAPID) at ODI. Specialist in maximising research and evaluation use, especially in large, complex projects. Works on governance, livelihoods, natural disasters, knowledge and power, research policy and practice.

Delegates from Germany, Hong Kong, India, Iran, Italy, Kyrgyzstan, Nepal and Russia

Dr Kanatbek Abdrakhmatov (Institute of Seismology, Academy of Sciences, Almaty, Kazakhstan and Bishkek, Kyrgyzstan)
Director of Institute of Seismology in Bishkek and Associate of Institute of Seismology, Almaty. Interests in earthquake geology, geomorphology, paleoseismology and earthquake hazards, with wide field experience throughout Central Asia. Leader of collaborative international projects in active tectonics, including GPS.

Dr Nicola D'Agostino (Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy)
Research scientist in tectonics, geodynamics, geodesy (GPS), earthquake seismology, gravity. Wide field experience in the Mediterranean and Italy, also Iran.

Dr Amod Dixit (National Society for Earthquake technology – NSET, Kathmandu, Nepal)
Executive Director of NSET. Earthquake engineer, with interests in social psychology, quantitative social research, communication and media. Involved in projects to increase public awareness of earthquake risk, and also to reinforce schools in Nepal.

Dr Galina Kulikova (Institute of Earth and Environmental Science, University of Potsdam, Germany)
Seismologist and specialist in historical earthquakes in the Tien Shan.

Dr Angela Landgraf (Institute of Earth and Environmental Science, University of Potsdam, Germany)
Geologist and paleoseismologist, with field experience in Iran, Mongolia, Argentina, Kyrgyzstan and Kazakhstan.

Dr Supriyo Mitra (Indian Institute for Science Education and Research – IISER, Kolkata, India)
Professor of Seismology, with wide field experience in India and Nepal, including post-earthquake studies in the Himalaya.

Dr Zahra Mousavi (Department of Earth Sciences, Institute for Advanced Studies in Basic Sciences – IASBS, Zanjan, Iran)
Research scientist specialising in space-based geodesy (GPS, InSAR) for tectonic and earthquake hazard studies. Experience with running GPS networks in many parts of Iran.

Dr Hamid Nazari (Geological Survey of Iran, Tehran, Iran)
Post-doctoral researcher in France and Cambridge, UK. Earthquake geologist, specialising in paleoseismology. Wide field experience in Iran.

Mr Surya Shrestha (National Society for Earthquake technology – NSET, Kathmandu, Nepal)
Deputy Executive Director of NSET. Structural and Earthquake Engineer and project leader in earthquake disaster preparedness. Also a leader in public earthquake education.

Dr Timothy Sim (Department of Applied Social Sciences, Hong Kong Polytechnic University, China)
Associate Professor, and specialist in Disaster Social Work, Director of the Collaboration Programme between Hong Kong Polytechnic University and the United Nations Office for Disaster Risk Reduction (UNISDR), 2015-2016.

Dr Alexander Strom (Geodynamics Research Center – Branch of JSC Hydroproject Institute, Moscow, Russia)
Interests in geology, geomorphology and remote sensing. Specialist in earthquake-induced landslides in Central Asia.

Dr Morteza Talebian (Geological Survey of Iran, Tehran, Iran)
Senior earthquake scientist in charge of the Tectonics group, and also Director of the Research Institute for Earth Sciences. Specialist in earthquake geology, seismology and tectonics, with wide field experience in Iran.

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Cover photo: Conference field trip to Ushkonyr, Kazakhstan. Victor Magdeyev/Shakhmardan Yessenov Foundation, 2016.

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